SYSTEM FOR COUPLING A MOBILE RADIO SERVICE BASE STATION TO AN ANTENNA

FIELD OF THE INVENTION

The present invention is generally directed to the coupling of one or more transmitters and receivers of a base station to an antenna. More specifically, the present invention is directed to a coupling system comprising multiple receive and transmit branch networks for coupling one or more transmitters and receivers of a base station in a commercial mobile radio service (CMRS) system.

BACKGROUND OF THE INVENTION

Personal Communication Service (PCS) is largely an enhancement of cellular radio telephone service which, in turn, is based on early two-way radio systems. In the simplest configuration, a receiver and transmitter share a common base station antenna for receiving and transmitting signals to and from mobile stations. Typically, the receiver and transmitter each use a separate frequency range for sending and receiving information. By grouping multiple pairs of frequency ranges, called frequency blocks, multiple mobile stations can share the same base station antenna infrastructure and provide advantages to the system operator.

One or more transmitters/receivers may be coupled to the antenna to accommodate different frequency blocks or different frequency ranges within a block. Current coupling implementations use components functioning as couplers, splitters, and duplexors to couple the antenna with the receiver and transmitter. Couplers typically combine two separate signals from two sources into one output source. In contrast, splitters accept one input signal and provide two nearly identical signals on separate outputs. Duplexors allow an input and an output signal on a common source to be separated at a common point into separate input and output channels.

Figure 1 is a functional block diagram that illustrates a typical prior coupling system **100** for two transmitters and two receivers sharing a common antenna in a commercial mobile radio service (CMRS) system. Referring now to Figure 1, an antenna **110** receives electromagnetic signals originating from mobile stations **125** and transmits such signals to the mobile stations. A hybrid coupler/duplexor **105** functions both as a coupler for combining signals from multiple transmitters **103** and as a duplexor to separate received signals **130** from transmit signals **128**.

The received signals from antenna **110** are output to the coupler/duplexor **105**, separated from the transmit signals **128**, and sent to a splitter **115**. The splitter **115** divides each received signal **130** output by the duplexor **105**, thereby providing two nearly identical signals **135** to receivers **120**. Because each output signal **135** contains all frequencies of the electromagnetic signals received by the antenna **110**, each receiver **120** typically filters unwanted signals. The transmit signals **128** originate from transmitters **103** and are combined by the coupler/duplexor **105** for transmission by the antenna **110**.

The duplexor function of the coupler/duplexor **105** separates the received signals from the transmit signals. Duplexors are traditionally assembled by connecting mechanically-tuned cavities together in a bandpass, band reject, or hybrid configuration. All duplexors must exhibit certain characteristics if optimum system performance is to be achieved. As shown in Table 1, these typical duplexor characteristics include:

TABLE 1

(1)	Operate in the specified transmit and receive frequency bands.
(2)	Handle total transmit power.
(3)	Provide adequate rejection of transmitter noise in the receive band.
(4)	Provide adequate isolation between the transmitter port and the receiver port to prevent receiver desensitization.
(5)	Provide minimum insertion loss, which is dependent upon the duplexor design and the frequency separation between the transmit and receive bands.

The coupler function of the coupler/duplexor **105** is also usually constructed of mechanically-tuned cavities designed to provide low transmission losses. The splitter **115**, on the other hand, is usually constructed with resistive components and has built-in amplifiers to compensate for any additional signal losses.

While the prior coupling system **100** is proven and well known, this coupling system carries the penalty of increased transmission losses as multiple transmitters are added. This addition of transmitters also requires the insertion of multiple couplers, which degrades the signal due to increase thermal noise. Because the components pass wideband signals, they offer no inherent advantages for adjacent signal rejection.

The configuration shown in Figure 1 is the conventional method of coupling transmitters and receivers in certain CMRS systems, such as AMPS-compatible systems. Because only two licensed cellular carriers are allowed in a given AMPS market, each cellular service provider usually deploys its own antennas and infrastructure. In contrast, PCS regulators allow up to six licensed providers in each PCS market. Because of increased difficulty in obtaining approval for constructing towers in urban areas, PCS providers now often share the same towers for mounting antennas. As the power of the received signal is proportional to the distance between the transmitting and

received antenna, co-location leads to one service provider's transmitted signals being received by another provider's antenna. Because of the multitude of providers operating in adjacent frequency blocks, as well as the close physical proximity of antennas, blocking adjacent signals is of greater concern to PCS providers than to cellular providers. Although conventional coupling technology can be used in PCS equipment to couple receivers and transmitters, prior coupling systems do not offer satisfactory signal interference rejection levels and signal to noise ratios for PCS systems. Moreover, the prior coupling systems suffer from increased transmission losses when multiple transmitter elements are added to the typical PCS system implantation.

In view of the foregoing, there is a need for an improved system to couple a transmitter and receiver of a CMRS system, such as a PCS system, to an antenna. The present invention provides a coupling system for CMRS systems that overcomes the disadvantages of the prior art while offering improved interference signal rejection, lower transmission losses, and improved signal-to-noise ratios.

SUMMARY OF THE INVENTION

The present invention provides a system for coupling a base station transmitter and a base station receiver to an antenna in or for a commercial mobile radio service (CMRS) system. The inventive coupling system includes at least a pair of receive branch networks and at least a pair of transmit branch networks. The receive branch networks couple the base receivers to the antenna via the receive path. Each receive branch network is operative to select a frequency range of the receive signals for reception by the base station receiver and to pass the receive signals to the receive branch networks located in the downstream portion of the receive path. The transmit branch networks couple the base transmitters to the antenna via the transmit path. Each transmit branch network is operative to select a frequency range of the transmit signals transmitted by the base transmitter for forwarding to the antenna and to accept all transmit signals forwarded by the transmit branch networks located in the downstream portion of the transmit path.

Each receive branch network typically includes the combination of a circulator and a filter, such as a band-pass filter. The circulator is

coupled to the receive path and can pass the receive signals to the filter and to another one of the receive branch networks in the downstream receive path. The filter, which is coupled between the circulator and the base receiver, selects a frequency range or block of the receive signals for reception by the base receiver.

Each transmit branch network typically includes the combination of a circulator and a filter, such as a band-pass filter. The filter, which is coupled between the circulator and the base transmitter, selects a frequency range or block of the transmit signals for eventual transmission by the antenna. The circulator is coupled to the transmit path and can pass the filtered transmit signals to the transmit path for delivery to the antenna. In addition, the circulator can pass transmit signals from the transmit branch networks located in the downstream transmit path to an upstream portion of the transmit path.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of the components of a prior coupling system for coupling transmitters and receivers to an antenna in a PCS system.

Figure 2 is a block diagram of the components of a coupling system for coupling transmitters and receivers to an antenna in accordance with an exemplary embodiment of the present invention.

Figures 3A and 3B, collectively described as Figure 3, are diagrams of exemplary receive and transmit branch networks respectively for the coupling system illustrated in Figure 2.

Figure 4A is a diagram illustrating the typical signal flow of a circulator for use with the coupling system shown in Figure 2.

Figure 4B is a diagram illustrating the typical construction of the circulator shown in Figure 4A.

Figures 5A, 5B, 5C, 5D and 5E, collectively described as Figure 5, are diagrams of the frequency response and signal levels for an exemplary branch network for the coupling system illustrated in Figure 2.

DETAILED DESCRIPTION OF THE EXEMPLARY EMBODIMENTS

The present invention is primarily designed for implementation in radio telephony systems, such as cellular-like commercial mobile radio service (CMRS) systems, and provides a coupling system for coupling a transmitter and receiver to an antenna. Advantageously, the coupling system provides lower signal loss and improved rejection of interfering adjacent signals when compared to conventional methods.

The configuration of an exemplary antenna coupling branch network for a Personal Communications System (PCS) system is depicted in Figure 2. As radio telephony systems inherently involve two-way communication, the preferred embodiment of this invention will be shown with signal coupling implemented for the same number of transmitters as receiver, *i.e.*, a balanced coupling system. Although the antenna branching network **200** may be utilized for a single transmitter/receiver pair, the preferred embodiment is configured for operation with two or more transmitter/receiver pairs coupled to a common antenna. An alternative exemplary antenna branching network can be implemented with a coupling system for an unequal number of receivers and transmitters, *i.e.*, an unbalanced coupling system.

An exemplary embodiment of the antenna coupling system **200** comprises a balanced number of receive and transmit branch networks **212** and **242**, respectively, within the receive and transmit paths. Each receive and transmit branch network **212** and **242** is respectively connected to a receiver **250** and transmitter **255**. The branch networks are typically allocated certain frequency ranges or blocks based on the operating ranges of the corresponding receiver or transmitter. Each receive branch network **212** comprises a circulator **212a** and a filter **212b**. The circulator **212a** is connected directly to the receive path, whereas the filter **212b** is connected between an output of the circulator **212a** and an input to the receiver **250**. Similarly, each transmit branch network **242** comprises a circulator **242a** and a filter **242b**. The circulator **242a** is connected directly to the transmit path, whereas the filter **242b** is connected between an input of the circulator **242a** and an output of the transmitter **255**.

A circulator **220**, coupled between the receive and transmit paths and to the antenna **225**, directs signal flow to and from the antenna. A filter **215** is preferably placed between the circulator **220** and the receive branch networks **212** to prevent undesired transmit-frequency signals from entering the receive path. Similarly, an isolator **230** is preferably placed between the circulator **220** and the transmit branch networks **242** to prevent undesired receive-frequency signals from entering the transmit path. Both the filter **215** and the isolator **230** pass desired signals; the filter passes receive signals to the nodes of the receive branch networks **212**, while the isolator passes transmit signals to the circulator **220**. Terminators **245** are coupled at the "ends" of the transmit and receive branch paths for the antenna coupling system **200**. These termination-type devices serve to terminate each path with an appropriate impedance, while minimizing undesirable signal reflections within the paths of the system **200**.

Turning now to a review of the operation of the antenna coupling system **200**, each transmitter **255** and receiver **250** is connected to branch networks **242** and **212** in the transmit and receive paths of the antenna coupling system **200**. A branch network in either the transmit or the receive path filters the specific frequency range associated with a transmitter or a receiver and allows the signal to be coupled with other signals provided to or from an antenna. For example, multiple branch networks can share an antenna **225**, with all receive branches **212** on one side of the configuration forming a receive path and all transmit branches **242** on the other side forming a transmit path. The circulator **220** couples signals to and from the antenna **225** onto the receive and transmit paths of the coupling system **200**. The circulator **220** allows transmit signals to be sent from the transmitter **255** to the antenna **225** and signals received from the antenna **225** to be sent to the receive path for reception by the receivers **250**.

In the transmit path, the transmit branch networks **242** are preferably connected to the isolator **230** which, in turn, is connected to the antenna circulator **220**. The isolator **230** prevents certain signals passed by the antenna **225** or otherwise present in the antenna circulator **220** from being sent to the transmitters **255** in the transmit path. In particular, the isolator **230** can attenuate any signals received by the

antenna **225** and prevents their introduction into the transmit branch networks **242**. However, the isolator **230** passes transmit signals supplied by the transmit branch networks **242** to the circulator **220** for transmission via the antenna. The isolator **230** is typically implemented as a circulator in which one port is terminated leaving the two other ports for receiving input signals and sending output signals. Any signals received by the input port in the upstream direction of the transmit path are sent by the isolator **230** to the output port, while reverse signals in the downstream direction are attenuated.

In the receive path, the receive branch networks **212** are preferably coupled to the antenna circulator **220** via a filter **215**. The filter **215** passes only signals of the frequencies associated with the receivers **250** to the receive branch networks **212**. The filter **215** passes all desired signals associated with the frequency ranges of the receivers **250** and attenuates signals originating from the transmit path or other signal frequencies received by antenna **225.**

For receive operations, the antenna **225** typically receives electromagnetic signals from one of the mobile radio stations of the CMRS system. The antenna **225** passes the received signals to the antenna circulator **220** which, in turn, sends the received signals to the filter **215**. The filter **215**, which is coupled to the receive branch networks **212,** filters the received signals and outputs filtered signals to the branches in the receive path. Each receive branch network **212** filters the received signals on the receive path based on the frequency range assigned to that branch network. In this manner, each receive branch network outputs a desired signal within a particular frequency range to the corresponding receiver **250**. For example, the first receive branch network **212**, which is directly connected to the filter **215**, separates a signal of a particular frequency range and passes the remaining signals to subsequent receive branches **212** in the downstream portion of the receive path. Each remaining receive branch network **212**, in turn, separates a signal of a different frequency range for processing by a corresponding receiver **250**. It will be appreciated that unique frequency ranges or blocks are assigned to separate receive branch networks **212** to support the processing of

signals within a specific frequency range by a corresponding receiver **250**, such as a channelized-type receiver.

For transmit operations, the transmit signal flow is opposite the receive signal flow because the transmit signal originates from the transmitter **255** and passes through a corresponding transmit branch network **242**. In turn, the transmit branch network **242** passes the transmit signal to the upstream portion of the transmit path for eventual radiation by the antenna **225**. It will be understood that this transmit signal can be coupled or summed with signals of other frequencies output by the remaining transmit branch networks **242**. In particular, the transmit signals from all transmit branch networks **242** located in the transmit path are passed to the antenna **225** for transmission to mobile stations of the CMRS system.

Each transmit branch network **242** is connected to one of the transmitters **255**. A transmit branch network **242** filters transmit signals issued by a corresponding transmitter based on the frequency range assigned to that branch network. In this manner, each transmit branch network outputs a desired signal within a particular frequency range from the corresponding transmitter **255**. For example, the first transmit branch network **242**, which is directly connected to the isolator **230**, filters a transmit signal within a particular frequency range and outputs that filtered signal to the upstream portion of the transmit path. In addition, this transmit branch network **242** also passes, to the isolator **230**, all transmit signals output by the remaining transmit branch networks located in the downstream portion of the transmit path. Each remaining transmit branch network **242** preferably filters a transmit signal of a different frequency range based on the frequency range assigned to its transmitter. It will be appreciated that unique frequency ranges or blocks are assigned to separate transmit branch networks **242** to support the processing of transmission of signals within a specific frequency range by a corresponding transmitter **255**.

Figure 3A illustrates a configuration for an exemplary section of a receive branch network and Figure 3B illustrates an exemplary section of a transmit branch network. Each branch network, whether receive or transmit, preferably comprises a combination of a bandpass filter and ferrimagnetic circulator. Turning first to Figure 3A, a representative

receive branch network **212** comprises a filter **315** coupled to a circulator **300**. This circulator comprises ports **301**, **302** and **303**. The opposite side of the filter is connected to one of the receivers **250**, whereas the remaining ports (**301** and **303**) of the three-port circulator are connected to the receive path. For an exemplary receive branch, signals from the antenna **225** enter the circulator **300** at port **301** and are sent to the input of the filter **315** via port **302**. The signals within the passband of filter **315** pass through to the receiver coupled to the filter **315**. Specifically, the output signals of filter **315** form the input to the receiver **250**. Those signals outside the passband of the filter **315** do not pass through, but are reflected back into port **302** of the circulator **300** and exit the circulator at port **303** to the next receive branch.

Turning now to Figure 3B, a representative transmit branch network **242** comprises a filter **317** coupled to a circulator **318**. The circulator **318** comprises three ports **311**, **312**, and **313**. One side of the filter **317** is connected to the port **312** of the circulator **318**. The opposite side of the filter **317** is connected to one of the transmitters **255**, whereas the remaining ports (**311**, **313**) of the three-port circulator are connected to the transmit path. For an exemplary transmit branch, signals originate from the transmitter **255** and are input to the filter **317**. The filter **317** outputs a filtered version of the transmit signal to the circulator **318**. The transmit signals, now filtered, enter the circulator at port **312** and are coupled with any signals that previously entered in port **311**. The signals exit at port **313** and travel in the upstream direction along the transmit path for delivery to the antenna **225**.

Turning now to Figures 4A and 4B, the circulator **300** (and circulator **318**) is preferably implemented as a three-port ferrimagnetic circulator that exhibits unique signal flow characteristics and typical port-to-port losses of less than 0.3 dB. The circulator illustrated in Figure 4B is typical of the type of circulators used in the UHF and low microwave frequency bands and incorporates a stripline junction. Two ferrite disks are set in between the case (ground plane) and the center metallic conductor (stripline). These ferrite disks form a single, low-order resonant mode cavity; however, when the ferrite material is

energized with a magnetic field this mode breaks into two resonant modes with slightly different resonant frequencies. The operating frequency of the circulator can be chosen by specifying the type and physical size of the ferrite material.

Circulators typically include an arrow on the component's case indicating the direction of rotation or signal flow through the circulator. As shown in Figure 4A, all energy entering the receive branch circulator **300** at port **301** will exit at port **302**, all energy entering port **302** will exit at port **303** and all energy entering port **303** will exit at port **301**. The port-to-port attenuation typically varies from 0.15 dB to 0.4 dB depending upon the circulator construction with representative values of less than 0.3 dB. If, at port **302** there is a mis-matched load, then some or all of the energy entering port **301** will be reflected in port **302** and will be sent to port **303** with little or no additional attenuation. This kind of phenomenon also occurs with an RF signal that is outside of a filter's passband. If port **302** is internally terminated with a mis-matched load, the configuration is known as an isolator. Any energy that tries to flow against the circulator rotation will be attenuated by typically 20 dB per section.

Figures 5A-5E illustrate the signals present at the ports of a three-port circulator, such as the circulator **300**, for a representative receive branch. As shown in Figure 5A, three signals with frequencies F1, F2 and F3, all of equal amplitude, enter the circulator **300** at port **301**. The signals pass through circulator **300** in the direction of rotation and appear at port **302**. All signals exit at port **302**. Because frequencies F1 and F3 are outside of the passband of filter **315**, they are reflected back by the filter into port **302** with a loss equal to the return loss of filter **315** at frequencies F1 and F3, as illustrated in Figure 5B. The F2 frequency will pass through the filter **315** as it is inside the filter's passband and signals F1 and F3 are attenuated, as shown in Figure 5C. Because the filter does not present a perfect impedance match, some of the F2 signal is also reflected back into port **302** at an attenuated level. The three signals travel and exit at port **303**, as shown in Figure 5D, onto the next circulator of a receive branch or until the terminator **245** for the receive path is encountered.

Referring again to Figure 5B, the filter **315** (and filter **317**) allows passage of the appropriate receive (transmit) frequency signals associated with the respective receivers (transmitters). The filter **315**, preferably implemented as a bandpass configuration, may be constructed as a ceramic filter, cavity filter, or other technology. Factors such as the power dissipation may determine the type of technology used to construct the filter. Bandpass filters typically have an insertion loss of less than 0.5 dB. There can be any number of branches configured in this system, as long as the operating frequency of the filter **315** is not repeated in any of the receive or transmit branches.

Bandpass filters typically exhibit two sets of characteristics, one set for "in-band" and another set for "out of band" performance. The important characteristics for filters used in the branching network are shown in Table II:

Table II

(1)	In-Band: amplitude/frequency response, return loss response, and the delay and linearity response.
(2)	Out-of-Band: rejection (sharpness of the filter skirt), and return loss response.

A brief description of the amplitude-frequency response and the return loss response characteristics assists in the understanding of how the filter **315** and the circulator **300** interact. The amplitude frequency response in Figure 5B illustrates the typical bandpass filter characteristics, as seen by the circulator **300**. The relative signal loss (amplitude-frequency response) over the band between the lower(f_{lco}) and upper(f_{uco}) cutoff frequencies is shown with respect to a reference frequency (F2). The smaller the relative loss (ripple), the flatter is the passband. The second characteristic is the out-of-band rejection. This characteristic measures the filter's ability to discriminate against signals that are close to, but outside of the passband. The steeper (more vertical) the filter skirt, the better the discrimination and the closer the frequency separation between the branch sections can be for the same out of band rejection specification. This improved rejection does not

come without a price, which is increased insertion loss and amplitude ripple inside the passband.

The primary filter characteristic that allows it to be used in a branching network configuration is the return loss response. This parameter indicates how well the filter performs with the circulator and it determines the signal loss as it passes through the circulator/filter combination to the next circulator. Specifically, the return loss response measures the change in the filter's characteristic impedance across a span of frequencies with respect to the designed passband characteristic impedance. This span of frequencies (F1 to F3) generally includes both the out-of-band and the in-band portions of the filter. The return loss response is inversely related to the amplitude response. Figure 5E shows the amplitude-frequency response (F1, F2 and F3) at port **303** due to the filter **315**/circulator **300** interaction.

The velocity of propagation of any RF signal that passes through a medium will be slowed down. If the RF signal is wideband and the medium is not uniform across the band, a portion of that signal will be slowed down more than another portion and result in distortion. Delay and linearity, or more appropriately, differential phase and differential gain are measurements of a device's ability to pass a wideband signal without detrimental distortion. Differential phase, expressed in degrees, is a measure of the rate of change in the phase angle of the leading edge of a modulated test tone as the signal is swept across the passband of the device under test. Similarly, differential gain, expressed in percent, is a measure of the rate of change of the modulated test tone signal's voltage (amplitude) as it is swept across the band.

These two parameters and the amplitude ripple determine whether the recovered signal can be successfully demodulated and decoded after it has passed through a non-linear (filter/circulator) device. These parameters are mentioned here to identify the need to consider these specifications when designing the components used in the branching network and selecting the frequency spacing.

The concept for combining or splitting certain signals works well when the signals, such as F1 and F3 of Figure 5B, are widely spaced. However, when these carriers are closer together, *e.g.*, in the F1A and F3B regions of Figure 5B, the signals fall on the knee, or slope, of the

return loss curve and are only partially reflected. The partial reflection causes greater loss and possible distortion as the signals pass through the branching network.

Unlike microwave radio systems operating in the lower microwave frequency ranges, PCS channel spacing is usually less than 1 MHz between adjacent channels and places stringent requirements on the filter. Furthermore, if a PCS base station is tuned to a different frequency block or sub-block, a change in the operating frequency of the filters is required. Rather than replace the filters of the branch networks, tunable filters can be utilized to provide flexibility in adapting receive and transmit branches to different frequency operation.

It will be understood that a coupling system using branching networks properly operates if each branch has a different operating frequency (passband). The advantages of the system over conventional methods is demonstrated if there is more than one transmitter and receiver per branch, as shown in Figure 2. A typical application would be to divide a PCS frequency block up into 3 or more (filtered) sub-band blocks. The number of block filters would depend upon the technology and the frequency plan being implemented.

Unlike the use of traditional technology, *i.e.*, couplers and duplexors, which pass wideband signals, transmission and reception of signals in the antenna branching network is limited to the frequencies of the branching network's bandpass filters. PCS systems may change the frequencies being used (called frequency hopping) as long as the hopping is restricted to frequencies (channels) inside the passband of the branching filter. These channels must be contiguous channels within the frequency block. The number of channels required within the block depends upon the technology and the frequency hopping scheme deployed.

The use of the antenna branching network provides various advantages. First, signal filtering occurs prior to receiver processing, resulting in a potential gain of 6 dB in the carrier to noise ratio. The same filtering also benefits signal reception by rejecting adjacent block signals as well as spurious signals from the transmitters. Furthermore, the circulator and filter components exhibit a lower overall transmission loss from the transmitter compared to current technologies. Lastly, the

overall noise floor improvement in the system compared to current technologies improves communication with mobile subscribers.

It will be appreciated by those skilled in the art that the branch networks for the embodiments of Figures 2 and 3 can be combined in numerous other ways than as illustrated. For example, an exemplary antenna coupling system can comprise only a pair of transmitters/receivers. The inventive technology also can be applied to cellular systems with the appropriate change in operational frequency aspects of the various components. Those skilled in the art that alternative adaptations and combinations of the components of the branch networks are possible and within the scope of the present invention.

The technology of the present invention relies on devices designed to manipulate electromagnetic signals based on their wavelengths. The physical size of these devices are physically inversely proportional to the frequency at which they operate. Because this PCS frequency spectrum comprises a higher frequency range than the frequency spectrum allocated to cellular, the components for a PCS-compatible embodiment are relatively small. The same components designed for cellular, would be much larger. Thus, it is feasible to use such technology for PCS, whereas it may be less practical for cellular.

The foregoing relates to the preferred embodiment of the present invention, and many changes may be made therein without departing from the scope of the invention as defined by the following claims.